

An application of data envelopment analysis to investigate the efficiency of lumber industry in northwestern Ontario, Canada

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Abstract: This study aims at exploring the technical efficiency of lumber industry in northwestern Ontario, Canada using data envelopment analysis (DEA). The DEA model analyzes relative technical efficiency of lumber mills with disproportionate inputs and outputs by dividing the 10-year time series data, for inputs and outputs of 24 lumber mills, over two periods (1999–2003 and 2004–2008). Four inputs, namely, material (log volume), labour (man-hours), two types of energy (hog-fuel and electricity), and one output (lumber volume) are used in this study. The trend analysis shows an annual reduction of 10%, 13% and 13% for lumber output, log consumption (input) and number of employees, respectively, during the period 1999–2008. The results from DEA with two scenarios with energy inputs and without energy inputs, for the two periods are found to be mixed and interesting. While some mills have improved their performance in terms of best use of available scarce inputs in the second period, some have shown negative per cent change in efficiency. In the with energy input and the without energy input scenario, some of the mills show a reduction in efficiency in the second period from the first period, with the highest estimated reductions of -13.9% and -47.6%, respectively. A possible explanation for these negative performances of mills in the latter period is the decline in production in the second period compared to the first period, where these mills were not able to adjust their inputs (mostly labour) as proportional lay-offs might not have been possible. These results provide policy makers and industry stakeholders with an improved understanding of the trends of efficiency and employment as well as reallocation opportunities of future inputs in order to increase benefits from this sector.

Key words: allocative efficiency; forest products industry; modelling; production inputs; technical efficiency

Introduction

Canada has about 402 million ha of forest land that accounts for about 10% of global forests and 30% of boreal forests in the world. It is the world's largest exporter of forest products where the forest products industry contributes about 2% to the gross domestic product of Canadian economy (CSLS 2003; CIEEDAC 2010; Natural Resources Canada 2012). Further, the province of Ontario has about 66.2% of its land area (71 million ha) covered by forest that generates about 200,000 direct and indirect jobs supporting 260 communities of which 40 are categorized as highly dependent on forest sector. The value of Ontario's forestry sector was estimated at CAD12 billion in 2009 of which pulp and paper products; sawmill, engineered wood and other wood product manufacturing; and value-added furniture/kitchen cabinet manufacturing were CAD 7.2 billion, CAD 3 billion and CAD 1.8 billion, respectively (OMNR 2012). Due to heavy presence of primary forest products industries in northwestern Ontario (NWO) region, the communities in NWO have historically benefitted from this sector. The forest sector has been the mainstay of NWO economy as it generates a significant amount of direct and indirect employment in the region. However, recent trends have shown that forest products industry of Canada in general and NWO in particular has been facing tremendous economic, trade and environmental pressures, and its competitiveness has significantly reduced (Shahi et al. 2011). These trends include increased competition from low cost producers and suppliers in developing countries; faltering economy and housing market in the United States, Ontario's biggest trading partner; historical trade disputes with the United States diminishing the federal and provincial governments' ability to stimulate the sector; global movement toward environmental regulations and sustainable forests; and shift in consumer preferences away from Ontario's traditional pulp and paper and sawmill products toward specialty manufactured goods. The combination of these trends

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has seriously impacted the profitability of Ontario's key forest industries and is threatening the future viability of the sector in this province. In order to make effective strategic decisions for forestry sector in NWO, it is essential that policy makers understand the unique production technologies and production trends of key forest industries in this region.

Previous productivity studies for Canada have either focused on forestry at the national level or compared only logging industry on a provincial basis using stochastic frontier analysis (SFA) techniques. Productivity studies examining the lumber industry include Nautiyal and Singh (1985), Singh and Nautiyal (1986), Constantino and Townsend (1986), and Martinello (1987). Manning and Thornburn (1971) studied the impact of capital and technological change while Buongiorno and Gilles (1980) estimated the implication of input costs, economies of scales and technological change on market prices in the Canadian pulp and paper industry. Sherif (1983) used an econometric model for the demand of factors of production in the pulp and paper industry. There have been some studies on the production structure of the Canadian logging industry at provincial and national levels (Woodland 1975; Rao and Preston 1983; Martinello 1985; Kant and Nautiyal 1997; Nanang and Ghebremichael 2006; Shahi et al. 2011). However, these studies using SFA techniques at the industry-level assume the producing firms are efficient, and with aggregated time series data being used in these studies, there is no way to diagnose the inefficiencies among the firms relative to each other.

Under this backdrop, we found no study focused on lumber mills in NWO and efficiency measurements with mill level information. Maintaining economic and employment benefits from the forest sector requires an in-depth understanding of the relative technical efficiency of individual mills. The relative technical efficiency of a mill, with disproportionate inputs and output combinations, measures how efficiently the inputs are being utilized in the mill to achieve the desired output in comparison to its peer group. This study aims at exploring the technical efficiency in the lumber industry using data envelopment analysis (DEA). The DEA model analyzes relative technical efficiency of lumber mills with disproportionate inputs and outputs by dividing the 10-year time series data, for inputs and outputs of 24 lumber mills, over two periods (1999–2003 and 2004–2008). DEA model is linear programming based approach, and is the first attempt to apply in the case of NWO lumber producing mills. DEA approach allows measuring the relative efficiency of producing unit with incommensurate inputs and outputs combinations, which is very effective in terms of analysing the improvements in using factors of production for more efficient productions as compared to the efficient peer group (Charnes et al. 1978; Banker et al. 1984; Byrnes et al. 1984; Ali and Seiford 1993; Andersen and Petersen 1993; Yin 2000; Lovell 1993, 1994). The results of our study will provide the policy makers and industry stakeholders with improved understanding of the trends of products and employment as well as the reallocation opportunities of factors of production in the future in order to increase the total benefits from this sector.

Materials and methods

Data and study area

Mill level production (lumber product) and consumption (wood logs) data sets provided by Ontario Ministry of Natural Resources (OMNR, 2010) were used for this study. The data set of OMNR (2010) was found to be incomplete for some mills, and so the data is reconciled with the previous published data by the ministry (OMNR, 2005). The time series is for ten years, 1999–2008 and contain detailed information about mills' annual returns in terms of volume of wood logs consumed, amount of products produced, etc. for the province of Ontario. The relevant data were extracted from the big excel files and later converted into Microsoft Access database using of Structured Query Language statements. As the focus is to analyse the trends of production and consumption of lumber and wood logs in NWO, only the data of mills in NWO were extracted from the large database of the province. Only the lumber mills were found to be relevant for DEA analysis as these mills have detailed input/output information with significant variations among the mills.

The annual data for lumber output and wood log input for 24 mills were obtained from OMNR (2005, 2010) data set. But, for some mills the data for all ten years were not available due to closure of mills in later years or merging of mill into another mill. The number of employees in each lumber mill for the period 1999–2003 was obtained from OMNR (2005) and for the later period this data were estimated based on linear and non-linear regression where data fitted well, and using unitary method where the relationships did not establish well. In order to get man hour data, 7.5 h working day for five days a week and 52 weeks of mill operation in a year were assumed. This gives 1950 hours from one employee in a year. Mill level estimates were not available for energy data for NWO. Therefore, national level energy data (CIEEDAC, 2010) for electricity and wood fuel being used in lumber mills were used for per m³ of lumber production over ten years at national level. This is under the assumption that the mills in NWO also have more or less similar energy use pattern as that of national level. Later, all these input estimates were divided by total output of lumber for each mill in order to get per m³ lumber coefficients for each input. Later the whole time series were divided into two period- first and second periods consisted of 1999–2003 and 2003–2008 respectively. The logic of separating the data set into two periods is that a significant decline in production of lumber from the year 2004 was observed; so it would be interesting to analyze the situation in terms of two periods. Finally, the data is averaged for each period to get the input coefficients for each input for two periods. Table 1 shows the descriptive statistics of the estimates of inputs for producing one m³ of lumber for two periods. The variation of these estimates is quite significant and hence the difference among the efficiencies among mills as described in the results section.

Table 1. Descriptive statistics of input variables for one m³ of lumber production

	Wood input (m ³)	Man hours	Electricity (GJ)	Wood fuel (GJ)
First period (1999–2003)				
Mean	2.415	6.063	0.353	0.734
Median	2.136	2.845	0.355	0.729
Standard Deviation	0.911	5.784	0.008	0.031
Range	3.804	18.142	0.033	0.151
Minimum	1.445	1.028	0.328	0.696
Maximum	5.250	19.170	0.361	0.847
Second period (2004–2008)				
Mean	2.199	8.223	0.366	0.829
Median	1.996	3.342	0.369	0.821
Standard Deviation	0.528	7.824	0.020	0.083
Range	2.280	23.265	0.089	0.355
Minimum	1.485	1.043	0.330	0.695
Maximum	3.765	24.307	0.419	1.050

With this segregation of input coefficients into two periods, three improvements in the data set and the analysis were achieved:

- (1) Averaging five years data minimizes the errors that creep into the data set for each year in mills.
- (2) As the data entered by OMNR is for annual return and it does not take into account the inventory information. By aver-

aging the data for five years it will significantly improve the estimates of input/output coefficients.

(3) This allows us to analyze the changes in relative efficiencies of mills in two periods as done by Kao (2000) to analyze the efficiency improvements in Taiwan's forestry reform programme.

The annual growth rates of input/output variables were calculated using the following exponential growth function.

$$P_t = P_0 e^{rt}$$

$$\Rightarrow r = \frac{\ln\left(\frac{P_t}{P_0}\right)}{t} \quad (1)$$

where, P_t = Final year value; P_0 = Initial year value, \ln = Natural logarithm, r = Growth rate, t = Number of years, e = Exponential

Fig. 1 shows the map of the study area (NWO) in context of North American geography. NWO consists of seven districts of Ontario, namely, Red Lake, Kenora, Dryden, Fort Frances, Thunder Bay, Nipigon, and Cochrane. This region has 20 forest management units (FMUs) with rich boreal forest that support various forest products industries historically.



Fig. 1 Map of study area (Source: OMNR, 2005)

Theoretical concept of efficiency

In general context, efficiency can be simply seen as the ratio between output and input which is less than or equal to one. In standard microeconomics context, firms face two types of efficiencies, namely, technical efficiency and allocative efficiency. Technical efficiency (TE) is related with the ability of a firm to produce maximal output with a given set of inputs, and allocative efficiency (AE) is the ability of a firm to use the inputs in optimal proportions, given their relative prices and the production technology. These two measures can then be combined to get the estimate of total economic efficiency (EE) of a firm (Farrell 1957; Charnes et al. 1978).

DEA and efficiency measurement

This section first describes some of the theoretical concepts based on micro-economics foundation relating to production systems and efficiency measures, and then presents a detailed description of DEA model along with a summary of data set of lumber mills.

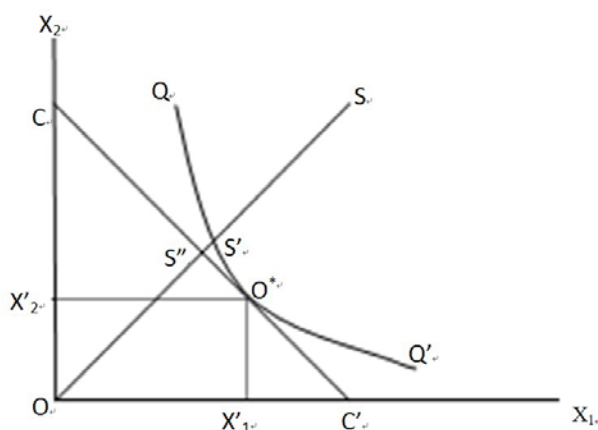


Fig. 2 Production system with one output and two inputs

In order to illustrate these efficiency concepts, we plot Fig. 2 with two inputs on two axes producing certain level of output, say, Y_1 . QQ' is an isoquant that represent all the possible combinations of two inputs giving the same amount of output, Y_1 . This implies that any point on the isoquant is technically efficient production of a firm. For example, if a firm uses inputs as indicated by the point S in order to produce the output Y_1 , then the firm is producing under technically inefficient condition. In this case, the firm's inefficiency is measured as distance SS' , i.e. the amount by which both the inputs could be proportionally reduced without a change in output (Y_1). Geometrically, the TE of the firm is expressed as $TE = OS'/OS$ which is less than one. From this, it can be deduced that for a firm to be technically efficient, this ratio must be equal to one. Thus, if the firm operates at point S' then it is technically efficient because it lies on the isoquant and has TE equal to one.

On the other hand, the isocost line CC' in Fig. 2 represents the

same cost for all the combination of inputs, and this is equal to the budget available for the firm to invest on the factors of production. The slope of the isocost line is the ratio of input prices w_1/w_2 , which helps in estimating the AE of the firm. The AE of the firm operating at S' is given by the ratio, OS''/OS' which is less than one. From Fig. 2, it is clear that the distance $S''S'$ is equivalent to the amounts of production cost that could be reduced to produce Y_1 level of production. This is possible only when, it is produced at the allocatively and technically efficient point O^* where the isocost is tangent to isoquant, and the optimal use of inputs X_1 with OX'_1 and X_2 with OX'_2 quantity is used to produce Y_1 output. The cost efficiency (CE) or EE is defined as the ratio of OS''/OS which is less than one in the case of the firm producing at the point S . The distance $S''S$ in Fig. 2 can be interpreted in terms of a cost reduction for the firm. The relationship among TE, AE and CE (or EE) can be expressed as in equation (2).

$$TE \times AE = \frac{OS'}{OS} \times \frac{OS''}{OS'} = \frac{OS''}{OS} = CE(EE) \quad (2)$$

Given these three types of efficiency measurements, the type of efficiency to be estimated depends on availability of relevant and the appropriate behavioural assumptions (Lovell 1994). In this study, the technical efficiency of lumber mills in NWO is analyzed as the panel data (combination of time series and cross-sectional) available for the study is only in material quantity terms and not in monetary terms. Four different model scenarios are run in order to diagnose various efficiencies of the production systems in lumber mills in NWO. If only input and output quantity data are available, only technical efficiency with either output or input orientation can be estimated. But, if data on factor and output prices are available, then cost efficiency can be estimated with its associated technical and allocative components using the DEA technique.

DEA model

The DEA models are useful to measure the relative efficiency of producing units, which is called decision making unit (DMU) in standard DEA literature, where there are incommensurate multiple inputs and outputs. The DEA model is appropriate where units can properly value inputs or outputs differently, or where there is high uncertainty or disagreement over the value of some input or outputs. A common problem in DEA model is the difficulty in seeking a common set of weights to determine relative efficiency. Charnes et al. (1978) proposed that DMUs can value inputs and outputs differently and therefore should be allowed to adopt different weights that make them more favourable comparison to the other units. With these assumptions on differential weights for inputs and outputs a DEA model is specified as shown in Equation (3). This type of model is called a linear fractional program (Charnes et al. 1978; Banker et al. 1984; Byrnes et al. 1984).

$$\begin{aligned}
 E_0 = \text{Maximize } & \frac{\sum_{i=1} u_i Y_{i0}}{\sum_{j=1} v_j X_{j0}} \\
 \text{Subject to } & \frac{\sum_{i=1} u_i Y_{ik}}{\sum_{j=1} v_j X_{jk}} \leq 1, \quad k = 1, 2, \dots, N \\
 & u_i, v_j \geq \varepsilon
 \end{aligned} \quad (3)$$

where, E_0 is the efficiency of the target DMU (lumber mill) to be maximized, X_{jk} the inputs for the production for the k^{th} mill, j the wood log, man hours, electricity and wood fuel, Y_{ik} the output of the k^{th} mill, i = lumber, v_j the weights for each inputs, u_i the weight for the output, and ε is a small non-Archimedean quantity.

In the above model, index 0 is designated to the DMU whose efficiency is to be estimated, and there are $N=24$ DMUs or mills in this study. E_0 is obtained as the maximum of a ratio of the weighted outputs to weighted inputs subject to the condition that similar ratios for every DMU be less than or equal to one. The u 's and v 's are variables to be determined under the constraint that the small non-Archimedean quantity ε is prevented from assigning 0 to unfavourable inputs and outputs (Charnes et al. 1979; Charnes and Cooper 1984). If this constraint is not imposed, some unfavourable inputs or outputs may be ignored in the evaluation. The solution to the above model gives a value E_0 , which represents the efficiency of a given mill relative to the all other lumber mills. If E_0 is one then the given mill is technically efficient relative to other; but if E_0 turns out to be less than one, then some other mill(s) is more efficient than this mill.

The DEA model described above in equation (3) has to be converted into linear form in order to solve it by linear programming methods. The linearization process is relatively straightforward, where the objective function is taken only as the numerator part of equation (2), and the denominator part is set to be equal to one. This is because, in maximising a fraction or ratio it is the relative magnitude of the numerator and denominator that are of interest and not their individual values. It is thus possible to achieve the same effect by setting the denominator equal to a constant and maximising the numerator (Dyson et al. 2001). The resultant linear program is as described below.

$$\begin{aligned}
 E_0 = \text{Maximize } & \sum_{i=1} u_i Y_{i0} \\
 \text{Subject to } & \sum_{j=1} v_j X_{j0} = 1 \\
 & \sum_{i=1} u_i Y_{ik} \leq \sum_{j=1} v_j X_{jk}, \quad k = 1, 2, \dots, N \\
 & u_i, v_j \geq \varepsilon
 \end{aligned} \quad (4)$$

Solving equation (4) with the constraints mentioned above will give us the estimates of efficiencies of the target units one by one. Thus, the model loop involves 24 runs (one for each mill) each giving estimates of efficiencies for 24 mills with corresponding input/output weights as solutions. These weights are the most favourable ones from the point of view of the target mill being maximized. As the objective function is varying for each mill, the weights obtained for each target unit would be different. These efficiency score obtained from DEA model can be considered as comparable to each other in relation to output versus combination of inputs. We used general algebraic modelling system (GAMS) computer language to solve the DEA problem.

Four different DEA models for lumber mills in NWO (one each for two study periods, *with and without energy input scenarios*) were run. The purpose of separating the two study periods is to diagnose the efficiency changes of mills before and after the crisis period in terms of reduction in production volume. The two scenarios of *with/without energy inputs* were selected to study their significant impacts on relative efficiency score due to lesser variability of per unit energy use for mills. Further, the implications of using and dropping of the variables with lesser variation (electricity and wood fuel as shown in Table 1) for efficiency score are important to note in this study (Sexton et al. 1986; Andersen and Petersen 1993; Smith 1997). The score are brought to the most efficient frontier by these less invariable factors as we seen the result section below. While presenting the efficiency results of 24 mills, mill codes (Mill1, Mill2 ..., Mill24) have been used to maintain the confidentiality of the production data of each mill in NWO.

Results and discussion

Trend analysis

There is a great deal of news about the mill closure in NWO region in the recent years due to several economic and political factors in Canada and USA. The number of facilitates (ranging from small to big ones) over the study period by product types in NWO are summarized in Table 2. This shows that there are more lumber mills in this region than the mills of other product types. However, number of lumber mills was found to be lesser in the later years due to closure problems as well as merging of some of the mills into a big company. This shows the present picture of forest products facilities in this region. Of the 28 lumber mills in NWO, relevant data for DEA modelling are available only for 24 mills; and hence this study only considers 24 lumber mills.

Fig. 3 presents the trends of lumber output and wood logs input (both in m^3 terms) and number of employee in lumber industry in NWO. In order to show a clear trend of number of employee over years, it is plotted on the secondary axis as the values of this variable are significantly lower than the other two variables. The sharp fall in the values for year 2008 are clearly visible in the graph. The lumber production shows increasing trend from 1999 up to 2002 and then starts declining from 2003 onwards except in the year 2005 (Fig. 3). Similar trend is noticed

in input and employee data. The figures of input and employee data for 2008 are significantly less than the figures for previous years. This can be attributed to a serious housing market collapse in USA, thereby reducing the demand of lumber in 2008, and partly due to the data recording problem by OMNR as some of the inventory would be recorded in the year 2009, which is not available at present to be included in the study. The results of the model run for the period 1999–2008 show significant negative annual growth rates of -10%, -13% and -13% for lumber output, wood log consumption (input) and number of employee, respectively. This is really a grave situation for the lumber industry in NWO where the main economic activities have been supported by lumber industries for long.

Table 2. Number of facilities over the study period in NWO

Facility Type	Number
Lumber	28
Pulp, Paper & Paperboard	9
Other Wood Fibre Products	2
Composite Solids and Panels	4
Whole tree chipper	4
Veneer Mill	2
Total	49

Note: Some mills have been closed or merged recently.

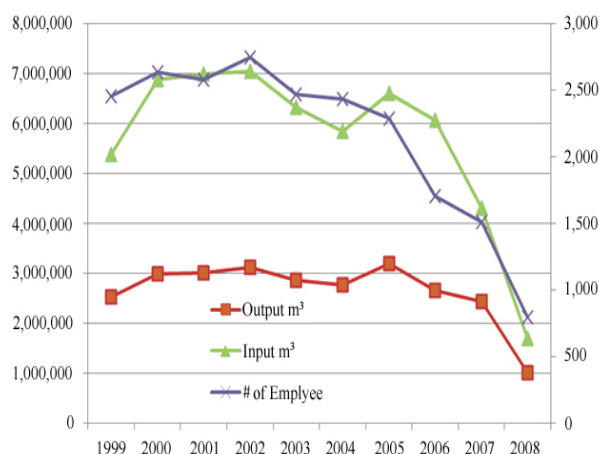


Fig. 3 Trends of input, output and employment in lumber industry in NWO. Note: Number of employee is shown on the secondary axis.

DEA results

Four different DEA models (one each for two study periods, *with and without energy input scenarios*) runs yield interesting results. Table 3 shows the technical efficiency scores along with the input/output weights for 24 mills with *energy input scenario*. It was found that Mills 4, 5, 6, 12, 15, 16, 20 and 21 are having efficiency score of one; implying that these mills are utilizing all the four inputs most efficiently relative to the rest of the mills. Further, the efficiency scores of the rest of the mills are also not much different from score 1. This is the problem with DEA results if some of the inputs have little variation and others have

higher coefficients for the production of same unit of output (Sexton et al. 1986; Smith 1997). The two energy inputs in the data set were having less variation over mills and other inputs like logs and man hours had high coefficients (Table 1). In this case, more weights were given to the favourable inputs (energy) as can be seen in weights columns of inputs of Table 3. Higher weights were given to energy inputs and lesser or near zero weights were given to logs and man hours. The resultant impact is that the efficiency scores became more or less similar to each other; the less variant favourable inputs (energy) pushed up the final results. The lesser variability (standard deviations) of energy data can also be seen in Table 1. The per unit output coefficient of energy inputs are also lesser than other input coefficients (Table 1). In order to get rid of this effect, we need to incorporate more accurate energy data at mill levels from mill source in the future to make the results more comparable.

Table 3. DEA results with all inputs for the first period (1999–2003)

Mill codes	Weights for inputs and output*				
	Efficiency	Logs	Man hours	Electricity	Wood Fuel
Mill1	0.971	0.004	0.002	1.665	0.510
Mill2	0.985	0.004	0.002	1.688	0.517
Mill3	0.996	0.004	0.002	1.706	0.523
Mill4	1.000	0.005	0.002	1.284	0.740
Mill5	1.000	0.000	0.011	1.976	0.392
Mill6	1.000	0.000	0.009	1.904	0.430
Mill7	0.992	0.002	0.006	1.791	0.473
Mill8	0.978	0.004	0.002	1.676	0.513
Mill9	0.984	0.004	0.002	1.686	0.517
Mill10	0.986	0.004	0.002	1.690	0.518
Mill11	0.991	0.000	0.009	1.888	0.426
Mill12	1.000	0.067	0.036	2.267	0.053
Mill13	0.973	0.004	0.001	0.000	1.361
Mill14	0.994	0.002	0.006	1.796	0.474
Mill15	1.000	0.006	0.005	1.748	0.496
Mill16	1.000	0.067	0.036	2.267	0.053
Mill17	0.996	0.004	0.002	1.706	0.523
Mill18	0.979	0.000	0.001	1.911	0.428
Mill19	0.998	0.002	0.006	1.802	0.476
Mill20	1.000	0.006	0.005	1.748	0.496
Mill21	1.000	0.004	0.002	1.714	0.525
Mill22	0.996	0.004	0.002	1.706	0.523
Mill23	0.976	0.000	0.000	2.252	0.286
Mill24	0.985	0.004	0.002	1.687	0.517

*The 0 weights are not exact zero in DEA due to ϵ constraint

In order to see the impacts of energy inputs in the efficiency score and check for the technical efficiency of mills with only more reliable mill level data of logs and man hours input, the model was run without energy inputs. The mode under this scenario produced significantly different results as shown in Table 4. Now, the efficiency ranges from 0.358 (Mill 6) to 1 (Mill 12, 15). This suggests that Mill 6 is operating only at around 36% utilization of its inputs relative to Mill 12 and 15; hence a good suggestion for input uses improvements for optimality of the production system for Mill 6. Further, while calculating the average of the efficiency scores of all the mills, we found about 0.99 and 0.70

scores for the *with energy* and the *without energy* scenarios, respectively. These estimates suggest for the overall performance of lumber industries in the first period (1999–2003). However, the average of 0.99 score in the with energy scenario is due to the fact that all most all mills score higher in this case as explained above.

Table 4. DEA results without energy inputs for the first period (1999–2003)

Mill codes	Weights for inputs and output*			
	Efficiency	Logs	Man hours	Lumber
Mill1	0.875	0.606	0.000	0.875
Mill2	0.513	0.355	0.000	0.513
Mill3	0.513	0.355	0.000	0.513
Mill4	0.673	0.266	0.194	0.673
Mill5	0.721	0.285	0.207	0.721
Mill6	0.358	0.000	0.348	0.358
Mill7	0.502	0.198	0.144	0.502
Mill8	0.782	0.541	0.000	0.782
Mill9	0.612	0.424	0.000	0.612
Mill10	0.698	0.483	0.000	0.698
Mill11	0.505	0.000	0.491	0.505
Mill12	1.000	0.395	0.288	1.000
Mill13	0.688	0.476	0.000	0.688
Mill14	0.722	0.285	0.208	0.722
Mill15	1.000	0.692	0.000	1.000
Mill16	0.927	0.641	0.000	0.927
Mill17	0.771	0.305	0.222	0.771
Mill18	0.468	0.324	0.000	0.468
Mill19	0.878	0.347	0.253	0.878
Mill20	0.848	0.335	0.244	0.848
Mill21	0.942	0.652	0.000	0.942
Mill22	0.666	0.263	0.192	0.666
Mill23	0.501	0.347	0.000	0.501
Mill24	0.714	0.494	0.000	0.714

*The 0 weights are not exact zero in DEA due to ϵ constraint.

The improvement in inputs in the most inefficient mill (Mill 6) in relation to the most efficient mills (Mill 12 and Mill 15) can be seen from Table 5. Here, Mill 6 is using 5.25 m³ of wood logs and 2.87 hours of labour to produce unit cubic meter of lumber, whereas the same output could be produced with significantly lesser amount of both inputs as done by mills 12 and 15. This is the evaluation possibilities provided by DEA results among the peer groups of DMUs. Interestingly, Mill 6 had score 1 when run with energy inputs (Table 3) due to lower wood fuel and electricity coefficients compared to other mills. Here, the log input data from mill 6 is bit suspicious; maybe some inventory problem or entry error on part of OMNR. But, once more accurate input estimates are made available; the present model can be run with resultant more efficient estimates.

Table 5. Comparison of inputs with efficient and inefficient mills

Mills	Logs (m ³)	Man hours
Mill6	5.250	2.870
Mill12	1.783	1.028
Mill15	1.445	1.492

Table 6 summarizes the efficiency scores and input/output weights of 24 mills in the second period. A similar pattern of results can be observed as in the case of the first period with energy inputs (Table 3). One contrasting result in this case is that more weights were given to electricity as this input coefficient is relatively lesser compared to others and wood fuel coefficient increased in the second period. We found Mill 1 as the least efficient (efficiency score - 0.836) and Mills 5, 10, 12, 14, 15, 19, 20 and 24 were having score 1 (Table 6). The results for Mill 11 are missing in the second period due its merging with Mill 12.

Table 6. DEA results with all inputs for the second period (2004–2008)

Mill codes	Weights for inputs and output*					
	Efficiency	Logs	Man hours	Electricity	Wood Fuel	Lumber
Mill1	0.836	0.130	0.000	1.771	0.000	0.836
Mill2	0.914	0.000	0.000	2.770	0.000	0.914
Mill3	0.917	0.000	0.021	2.457	0.000	0.917
Mill4	0.962	0.004	0.022	2.548	0.000	0.962
Mill5	1.000	0.000	0.022	2.679	0.000	1.000
Mill6	0.908	0.004	0.021	2.404	0.000	0.908
Mill7	0.992	0.000	0.022	2.658	0.000	0.992
Mill8	0.973	0.000	0.000	2.949	0.000	0.973
Mill9	0.942	0.146	0.000	1.996	0.000	0.942
Mill10	1.000	0.032	0.020	2.531	0.000	1.000
Mill11	Mill 11 merged in this period into Mill12					
Mill12	1.000	0.000	0.153	2.206	0.000	1.000
Mill13	0.917	0.000	0.000	2.777	0.000	0.917
Mill14	1.000	0.000	0.052	2.537	0.000	1.000
Mill15	1.000	0.032	0.020	2.531	0.000	1.000
Mill16	0.875	0.000	0.000	2.652	0.000	0.875
Mill17	0.953	0.004	0.022	2.522	0.000	0.953
Mill18	0.921	0.143	0.000	1.953	0.000	0.921
Mill19	1.000	0.093	0.134	0.104	0.743	1.000
Mill20	1.000	0.093	0.134	0.104	0.743	1.000
Mill21	0.861	0.000	0.000	2.610	0.000	0.861
Mill22	0.974	0.004	0.022	2.579	0.000	0.974
Mill23	0.991	0.000	0.000	0.000	1.426	0.991
Mill24	1.000	0.000	0.000	3.030	0.000	1.000

*The 0 weights are not exact zero in DEA due to ϵ constraint

Similar to the results of the first period without energy inputs, significant variations in terms of efficiency scores among 23 mills in the second period were obtained, while running the model without energy inputs. Table 7 shows the results of model for efficiency scores and corresponding weights of inputs and outputs as variables of the model run. Table 7 shows that Mill 23 is the least efficient mill with score of 0.394, and again Mill 12 and 15 are the most efficient with the score of 1 among all the lumber mills in NWO for the second period. The reason behind this is again the inefficient use of inputs by Mill 23 (3.765 m³ of logs and 15.211 man hours) as against the most efficient use of inputs by Mill 12 (1.753 m³ of logs and 1.043 man hours) to produce unit amount of lumber. The corresponding weights for inputs for inefficient and efficient mills were also observed. For Mill 23, the weight assigned to labour is equal to ϵ (very small number set as constraint to weight) because of higher value of

man hours being used to produce a unit quantity of lumber. But, for the efficient Mill 12, the weights are distributed to both the inputs. These results suggest the benchmarking of input uses with respect to the most efficient (score 1) mills according to the scores of each mill as explained in the case of first period results without energy inputs. Further, the overall efficiency scores of lumber industry in the second period as reflected by the average scores were 0.95 and 0.73 in the with energy and the without energy scenarios, respectively. Interestingly, the average efficiency score in the without energy scenario, which we believe is more policy relevant in this study, has increased in the second period suggesting some improvement in the overall performance of the industry in the latter period.

Table 7. DEA results without energy inputs for the second period (2004–2008)

Mill codes	Weights for inputs and output*			
	Efficiency	Logs	Man hours	Lumber
Mill1	0.748	0.504	0.000	0.748
Mill2	0.630	0.424	0.000	0.630
Mill3	0.619	0.417	0.000	0.619
Mill4	0.767	0.517	0.000	0.767
Mill5	0.705	0.321	0.137	0.705
Mill6	0.744	0.501	0.000	0.744
Mill7	0.534	0.243	0.104	0.534
Mill8	0.675	0.454	0.000	0.675
Mill9	0.772	0.520	0.000	0.772
Mill10	0.767	0.517	0.000	0.767
Mill11	Mill 11 merged in this period into Mill12			
Mill12	1.000	0.455	0.194	1.000
Mill13	0.567	0.382	0.000	0.567
Mill14	0.929	0.422	0.180	0.929
Mill15	1.000	0.673	0.000	1.000
Mill16	0.486	0.327	0.000	0.486
Mill17	0.780	0.355	0.151	0.780
Mill18	0.818	0.551	0.000	0.818
Mill19	0.904	0.411	0.175	0.904
Mill20	0.860	0.391	0.167	0.860
Mill21	0.630	0.424	0.000	0.630
Mill22	0.847	0.385	0.164	0.847
Mill23	0.394	0.266	0.000	0.394
Mill24	0.687	0.463	0.000	0.687

*The 0 weights are not exact zero in DEA due to ϵ constraint

Most of the DEA studies so far have used cross-sectional data of DMUs to analyze the efficiencies of DMUs for the given point of time. But this lacks the notion of efficiency comparisons for the same DMUs into two different points of time. However, by separating the panel data into two periods, this study has been able to analyze the changes in relative efficiencies of mills in two periods as done by Kao (2000) to analyze the efficiency improvements in Taiwan's forestry reform programme. However, the results of this study should be taken with a note of caution; it is quite possible that a DMU which has significantly improved in terms of inputs use in one period might end up with the same efficiency score at the next period simply because the other DMUs also improved their input use efficiency proportionally.

Nevertheless, the comparison of efficiencies will provide us with important information in terms of changes in efficiencies of the given DMU in two points of time (Kao 2000). The interesting results for Mills 12 and 15 are that they both had zero percent change in both the scenarios; indicating that the mills are using their resources most efficiently in both periods under both scenarios relative to their peers.

Table 8 summarizes the comparisons of percent changes in efficiencies of lumber mills between scenarios (with energy and without energy inputs) for each period and in two periods. The results are mixed in terms of improvements in efficiency. The negative percent estimates of Table 8 show that the mill has performed poorly as compared to the with energy input scenarios and the previous period, and the positive estimates indicate that the efficiency has increased between the scenarios and the periods. The interesting results of percent change in efficiency for Mill 12 and 15 is zero in both the scenario; indicating that the mills are using their resource most efficiently in both the periods under both scenarios relative to their peers. With energy scenario, more mills show negative changes in efficiency with highest estimate of about -14% for Mill 1 and Mill 21. But, without energy input scenario, the highest negative change is for Mill 16 followed by Mill 21. The possible explanation of these negative performances of mills is that due to decline in production in the second period compared to the first one; these mills were not able to adjust their inputs (mostly labour) as the mass lay-offs might not have been possible for these mills. This means they were running with more man powers relative to the production level. Further, the percentage changes in efficiency scores for each period from the with energy scenario to the without energy scenario were found to be negative as explained by the fact that in the with energy input scenario the efficiency scores got inflated by relatively homogenous energy input coefficients (as explained above).

We can also see some mills improving their efficiency in the second period mostly in without energy input scenario (Table 8). The highest improvement in percent term is found to be for Mill 6 followed by Mill 18, Mill 14, Mill 9, Mill 2 and Mill 3, respectively. These mills were able to adjust their factors of production over time by learning from previous production trends relative to their peers; and hence improvements in technical efficiency scores. These results can, therefore, suggest a good baseline understanding of proportionate use of inputs to get the maximum outputs for the lumber mills in NWO. The last row of Table 8 provides the information about the percentage changes in average efficiency scores for the lumber industry in NWO between scenarios for each period and between two periods by scenarios. The last cell of the table suggests that overall the lumber industry has improved by 8.26% in terms of its technical efficiency from the first period in the case of the without energy input scenario.

Given the accuracy level of input data in this study, it can be concluded that the model results without energy inputs for both the periods as shown in Table 4 (for the first period) and Table 7 (for the second period) are more policy relevant. The model results with all four inputs are also important to see the sensitivities of the efficiency scores and weights when some inputs are less

varied and less in quantity compared to some others. The end results are: i) giving more weights to the lesser values of inputs, and ii) the variation in efficiency score is offset by the lesser variation in some of the inputs (e.g., electricity and wood fuel in our study).

Table 8. Changes in efficiency in two scenarios and periods by mills in NWO

Mill Codes	% Changes			
	First Period	Second Period	With Energy	Without Energy
	between two scenarios	between two scenarios	Between two periods	between two periods
Mill1	-9.89	-10.53	-13.90	-14.51
Mill2	-47.92	-31.07	-7.21	22.81
Mill3	-48.49	-32.50	-7.93	20.66
Mill4	-32.70	-20.27	-3.80	13.97
Mill5	-27.90	-29.50	0.00	-2.22
Mill6	-64.20	-18.06	-9.20	107.82
Mill7	-49.40	-46.17	0.00	6.37
Mill8	-20.04	-30.63	-0.51	-13.68
Mill9	-37.80	-18.05	-4.27	26.14
Mill10	-29.21	-23.30	1.42	9.89
Mill11	-49.04	Mill 11 merged to Mill 12 in the second period		
Mill12	0.00	0.00	0.00	0.00
Mill13	-29.29	-38.17	-5.76	-17.59
Mill14	-27.36	-7.10	0.60	28.67
Mill15	0.00	0.00	0.00	0.00
Mill16	-7.30	-44.46	-12.50	-47.57
Mill17	-22.59	-18.15	-4.32	1.17
Mill18	-52.20	-11.18	-5.92	74.79
Mill19	-12.02	-9.60	0.20	2.96
Mill20	-15.20	-14.00	0.00	1.42
Mill21	-5.80	-26.83	-13.90	-33.12
Mill22	-33.13	-13.04	-2.21	27.18
Mill23	-48.67	-60.24	1.54	-21.36
Mill24	-27.51	-31.30	1.52	-3.78
Average	-29.07	-23.22	-3.75	8.26

Conclusion

Even though there are many studies on forest products industries productivity and trends at national and provincial levels in Canada, there is dire lack of studies on baseline information about different forest products industries in NWO and efficiency measurements with mill level information. The trends in forest products industry and employment situation along with a detailed data envelopment analysis for lumber mills of NWO are studied in this paper. First, a trend analysis of lumber products industry in term of input/output for this industry is presented. Second, a detailed DEA model used to analyze the technical efficiency of lumber mills for two periods is described by dividing the ten years time series data for input and output of 24 lumber mills in two periods (1999–2003 and 2004–2008) with average estimates of five years each. The trend analysis shows significant negative annual growth rates of lumber output, log volume consumption and employment in the lumber industry during the period of 1999–2008. This is really a grave situation for the lumber indus-

try in NWO, where the main economic activities have been supported by lumber industries for long.

The results from DEA analysis with two scenarios (with energy inputs, and without energy inputs) for two periods are found to be mixed and interesting. While some mills have improved their performance in term of best use of available scarce inputs in the second period, some have done opposite as indicated by the negative percent estimates of change in efficiency. The interesting results for Mills 12 and 15 are that they both had zero percent change in both the scenario; indicating that the mills are using their resource most efficiently in both the periods under both scenarios relative to their peers. In the with energy scenario, more mills show the negative changes in efficiency. But, in the without energy input scenario, the highest negative change is for Mill 16 followed by Mill 21. The possible explanation of these negative performances of mills is that due to decline in production in the second period compared the first one; these mills were not able to adjust their inputs (mostly labour) as the mass lay-offs might not have been possible for these mills. This means they were running with more man powers relative to the production level.

Some mills are also seen improving their efficiency in the second period mostly in without energy input scenario. These mills are able to adjust their factors of production over time by learning from previous production trends relative to their peers; and hence improvements in technical efficiency scores. The average estimates of efficiency scores and the percentage changes indicate the overall performance of lumber industry in different scenarios and periods, thereby giving important information for the policy makers.

Given the accuracy level of input data in this study, it can be concluded that the model results of the without energy inputs scenario for both the periods are more policy relevant. The model results with all four inputs are also important to see the sensitivities of the efficiency scores and weights when some inputs are less varied and less for per unit output compared to some others. The end results are: i) giving more weights to the lesser values of inputs, and ii) the variation in efficiency score is offset by the lesser variation in some of the inputs (e.g., electricity and wood fuel in our study). These results will provide the policy makers and industry stakeholders with improved understanding of the trends of products and employment as well as the reallocation opportunities of factors of production in the future in order to increase the total benefits from this sector.

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